

CleanFleet FINAL REPORT



December 1995

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OCCUPATIONAL HYGIENE

The CleanFleet project was a 24-month demonstration of FedEx delivery vans operating on each of four gaseous or liquid alternative fuels: compressed natural gas (CNG), propane gas, methanol M-85, and California Phase 2 reformulated gasoline (RFG). Two electric vans were also demonstrated. Each alternative fuel fleet was operated from a different FedEx station site in the Los Angeles area. Gasoline-fueled control vans located at each site allowed for comparisons between fleets.

The alternative fuels used in the CleanFleet project differ from conventional fuels both in their physical properties and in their potential health effects. These differences can result in occupational health implications for fleet users of these fuels. Therefore, as part of the CleanFleet project, a limited occupational hygiene survey was performed.

Introduction

This is the sixth volume of the CleanFleet Findings, the final report on the CleanFleet alternative fuels demonstration project. The demonstration was conducted at five FedEx facilities (sites) in the Los Angeles area. The geographic extent of the demonstration is illustrated in Figure 1, which shows the service areas of vans for each alternative fuel. Each site also had control vans (i.e., unmodified production versions of the CleanFleet vehicles built to operate on unleaded gasoline) from each manufacturer of the alternative fuel vans.

The CleanFleet project was conducted in a “real-world” setting. FedEx used the 111 vehicles day-in and day-out in its rigorous delivery service operations. Only vehicles that could withstand the rigors of FedEx requirements for performance and reliability were accepted into the demonstration. All fuels were demonstrated successfully over the 24-month demonstration.

Data were collected on emissions, vehicle inspections, performance tests, vehicle activity, fuel consumption, oil and fuel analysis, repairs/maintenance, accidents and incidents, employee experience, and weather conditions. This volume of the CleanFleet Findings focuses on the occupational hygiene experience of the CleanFleet project.

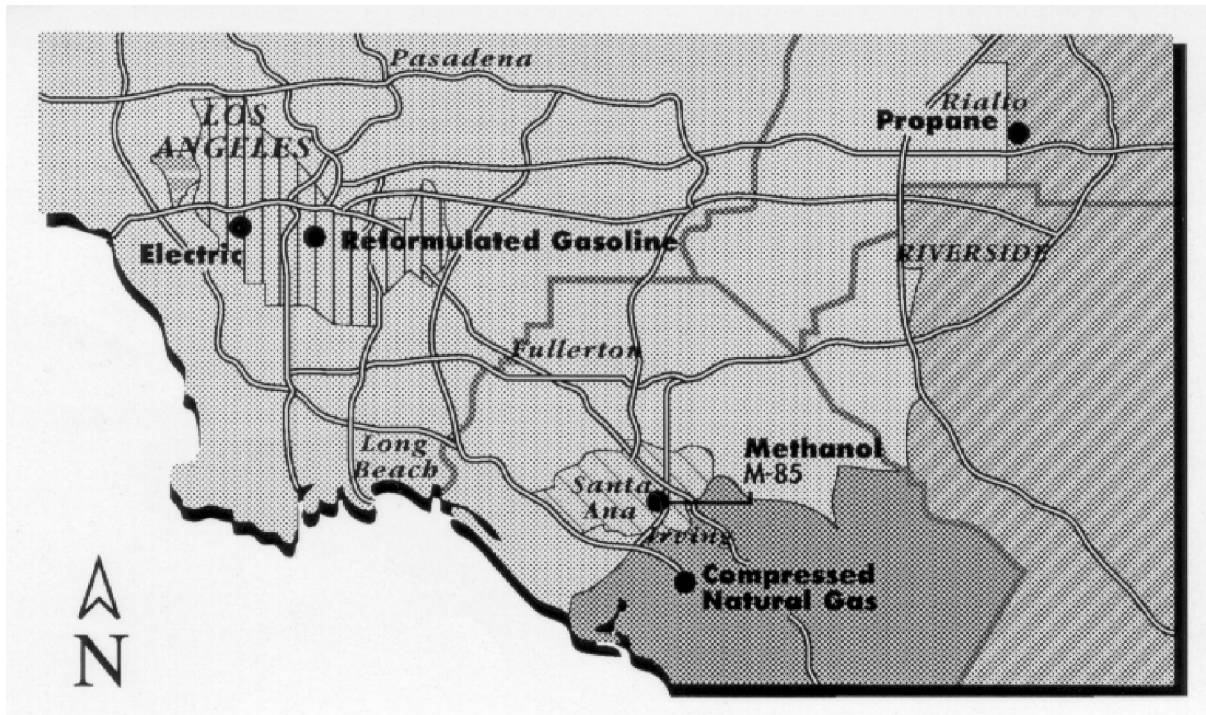


Figure 1. Service Areas of Vans for Each Fuel Tested (Only a portion of the service area for the propane-fueled vans is shown.)

Overview

As part of the CleanFleet project, a limited occupational hygiene survey was made to

- Obtain data on the exposure of FedEx employees to vapors from the fuels themselves during fueling.
- Obtain data on the formaldehyde concentration in the FedEx workplace near the methane- and methanol-fueled vehicles during morning start-up and pull-out and on exposure to carbon monoxide (CO) from vehicle exhaust during indoor operations.

The overall objective of this limited, “scoping” study was to identify the major safety and occupational hygiene issues connected with the fleet use of alternative fuels. The study did not include a formal hazard analysis of the vehicles or fuel dispensing equipment. For some cases, the measured exposure levels were so low that the likelihood of occupational hygiene problems would be slight; for other cases, higher values were observed. Additional measurements would be required to define more exactly the conditions under which high concentrations occur and the frequency of those conditions within fleet operations such as FedEx.

Background on Fuel Dispensing Facilities

Prior to describing measurements made during fuel dispensing, it is useful to look at the type of dispensing equipment used for each fuel.

Compressed Natural Gas (CNG). The fleet consisted of 21 vans located at the FedEx demonstration site in Irvine, CA. The vans were fueled each evening to a nominal pressure of 20 MPa. The CNG fueling system consisted of a gas meter, an electric-drive natural gas compressor, a cascade, and a fuel dispenser with a vented Sherex 1000 fuel nozzle. Each of these parts of the compressed natural gas fuel system was located at different places on the property: the CNG fueling island was about 35 meters from the natural gas compressor and about 12 meters from the CNG storage cascade and the FedEx building.

Although compressed natural gas fuel systems are designed to be closed systems, exposure to natural gas can occur because

- The connections and seals are not perfect, and the high fuel pressure promotes leakage, even through small paths.
- Some gas is necessarily trapped between the fuel nozzle and the fuel receptacle connection on the vehicle. When the connection is broken at the conclusion of fueling a vehicle, this trapped gas is released.

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Propane Gas. The propane gas-fueled fleet consisted of 20 vans located at the FedEx demonstration site in Rialto, CA. Generally, all 20 propane gas vans were fueled each evening. The vans were equipped with auto-stop fill devices that shut off the supply of fuel when the tanks reached 80 to 85 percent of capacity. However, due to existing regulations, the tanks were also equipped with a manual vent valve used to sense when the liquid level in the tank had reached the fill level.

The fuel dispensing system for propane consisted of a 4,000-liter propane storage tank, a pump, and a fuel dispenser. The propane dispenser was located about 15 meters from the FedEx building.

Although propane gas fuel systems basically are closed systems, exposure to fuel vapor can occur not only because of leaks or making and breaking fueling connections, but also because the liquid level valve is required to be open during fueling.

Methanol M-85. The methanol M-85-fueled fleet consisted of 20 vans located at the FedEx demonstration site in Santa Ana, CA. Generally, all 20 methanol M-85 vans were fueled each evening. The vans were fueled from a 15,000-liter, aboveground, vaulted storage tank that was installed for the CleanFleet project and located adjacent to the building. The fuel pump, dispenser, and fuel nozzle incorporated a standard, Stage II vapor recovery system. However, if the vapor recovery system does not capture all the fuel vapors, exposure to fuel vapors can still occur.

Reformulated Gasoline (RFG). California Phase 2 reformulated gasoline (RFG) was used to fuel a fleet of 21 FedEx vans located just south of downtown Los Angeles. This reformulated gasoline had a lower aromatic and olefin content, less sulfur, and a lower Reid vapor pressure (RVP) than current gasolines. The RFG contained 10.5 volume percent methyl-tert-butyl ether (MTBE). Both the RFG regular unleaded gasoline and the RFG were stored on the premises in underground storage tanks. The two fuels were supplied from adjacent dispensers located on the same fueling island. Both the regular unleaded and the RFG fuel dispensers were equipped with Stage II vapor recovery systems.

Background on Indoor Fleet Operations

As part of the CleanFleet project, limited survey measurements were made of the indoor levels of formaldehyde and carbon monoxide in FedEx buildings that housed alternative fuel vehicles.

Many operators of medium duty fleets, including FedEx, load, unload, and store their vehicles indoors. Such indoor operations can provide productivity and security advantages over outdoor operations. Although the indoor operation of a given vehicle is generally brief because the vehicle does not need to be started until it is loaded and ready to go, both formaldehyde and CO emissions are more severe when the engine is first started and is still cold. Catalytic converters can remove formaldehyde and CO by completing the oxidation; however, they are not effective until they reach their operating temperature. Thus, the full benefit of catalytic converters is not available during start-up and pull-out.

The objective of this limited air sampling effort was to document the concentrations of indoor formaldehyde and/or CO in this type of indoor fleet operation and therefore the importance of seeking alternative fuel vehicle combinations with low formaldehyde or CO upon start-up.

The formaldehyde measurements were made at the FedEx demonstration sites in Irvine and Santa Ana because the fuels used at these sites, natural gas and M-85, are composed mainly of chemical constituents with one carbon atom. These are chemical precursors of formaldehyde, the aldehyde with one carbon atom.

At each demonstration site, the alternative fuel fleet comprised from 15 to 25 percent of the total FedEx fleet. Because FedEx operations could not be modified to start only vehicles of one fuel type, the measured formaldehyde and CO levels cannot be ascribed solely to the alternative fuel. However, CleanFleet alternative fuel vehicles were clustered at certain parking locations along the package sorting belt, and these locations were chosen as locations for air sampling.

Procedures for Monitoring Exposure to Fuel Vapors

Sampling Procedures. Although all employees could potentially be exposed to fuel vapors, in practice, exposure is concentrated among employees who fuel vehicles. Because many vehicles are fueled in close succession, a fleet fueling operator has the potential for several hours of nearly continuous exposure to the fuel. Thus, the fuel vapor exposure sampling was centered on the fueling operation: for each fuel, multiple fuel vapor measurements were made on the fueling island in or near the breathing zone of the fuelers during a normal evening fueling.

Additional measurements also were made to characterize fuel vapor levels in the vicinity of aboveground fuel storage and dispensing equipment and to respond to specific concerns voiced by FedEx employees. Thus, added measurements of natural gas were made near the natural gas compression and storage facility, added propane measurements were made in the interiors of propane-fueled vans that had been refueled and parked overnight, and added methanol vapor measurements were made indoors near the exhausts of operating methanol-fueled vehicles. For a few tests, in order to gain some insight into the source strength, the sampling wand was held near the fuel nozzle and filler neck of the vehicle. Where possible, all measurements were made downwind of the suspected source of fuel vapors.

Analytical Procedures. The concentrations of fuel vapor in the air were determined using a MIRAN 1B gas analyzer. The MIRAN analyzer is a portable, single-beam, quantitative infrared spectrometer equipped with an on-board sample pump to draw air samples into the instrument for analysis. This instrument has a precision of ± 1 ppm and is estimated by the manufacturer to have an accuracy of ± 5 percent. The MIRAN updates the concentration readings approximately every five seconds; the output from the MIRAN was fed to a data acquisition system that provided a digital record of the readings.

For each fuel, representative chemical species were selected for monitoring. Table 1 summarizes these choices and lists the infrared (IR) wavelengths used for the fuel vapor measurements.

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Table 1. Chemical Species Chosen for Fuel Vapor Monitoring

CleanFleet Fuel	Target Species Measured	Scale Calibration Range, ppm	IR Wavelength Band Used, μm
Compressed Natural Gas	Methane ^(a)	0-100 0-1,000	7.70
Propane Gas	Propane	0-2,000	3.37
Methanol M-85	Methanol	0-200	9.70
Gasoline: hydrocarbons	Octane ^(b)	0-100	3.39
Gasoline: oxygenate	MTBE (oxygenate)	0-100	9.53

^(a) Because the compressed natural gas averaged 95 percent methane, the methane concentration provided an excellent estimate of the amount of natural gas present.

^(b) Paraffin hydrocarbons are relatively abundant in gasoline vapor and therefore constitute good overall measure of exposure to the fuel.

Procedures for Monitoring Indoor Air

Sampling Procedures. Formaldehyde sampling was accomplished by using two battery-powered pumps that drew air at the rate of 0.2 L/min into impingers filled with distilled water. The air samplers were located about one meter away from the belt used to sort packages. Because all FedEx couriers are present at the side of the belt to sort packages, this location was believed to be representative of workplace exposures. The height of the samplers, about two meters above floor level, was somewhat above the breathing zone, but was necessary to protect the pumps and glass impingers from inadvertent damage during package-sorting activities. Because the alternative fuel vehicles tended to be clustered at certain locations along the package-sorting belt, the samplers could be located near clusters of vehicles using the alternative fuel.

The indoor air formaldehyde samples were taken during the morning start-up and pull-out. The samplers were started when the first trucks started to leave the building and stopped when most of the trucks near the sampler had departed. This time ranged from 10 to 30 minutes.

CO monitoring was also performed during the morning start-up and pull-out. For CO monitoring, the MIRAN analyzer was located underneath the package-sorting belt, with the sampling wand about one meter above floor level. Because all FedEx couriers are present at the side of the belt to sort packages, this location was believed to be representative of workplace exposures. While this height is somewhat below

the normal breathing zone, it was necessary to locate the instrument out of the way of the package-sorting activities. Also, FedEx couriers often place packages on the floor temporarily, thus extending the breathing zone downwards.

Analytical Procedures. The formaldehyde concentration in the distilled water was determined by using the 3-methyl-2-benzothiazolinone hydrazone (MBTH) reagent to form a blue-colored product, then using a spectrophotometer to measure the color intensity at 628 nm.⁽¹⁾ The MBTH reagent also responds to other aldehydes, but with much reduced sensitivity, because other aldehydes are not collected efficiently by distilled water alone.⁽²⁾ The spectrophotometer reading was compared to a calibration curve developed from diluted certified formaldehyde standard solutions. A correction factor of 1.11 was applied to account for an assumed impinger efficiency of 90 percent.⁽³⁾

Use of the impinger-MBTH method allowed excellent sub-ppm sensitivity combined with the ability to analyze samples in the field. This allowed verification prior to leaving the site that sampling times and rates were acceptable.

CO measurements were made using the MIRAN 1B gas analyzer described above. For CO, a wavelength of 4.7 μm was used.

Results

Results for the occupational hygiene measurements are summarized in two parts. Results for the fuel vapor measurements are presented first, followed by results for the indoor air measurements.

Fuel Vapor Concentrations

Compressed Natural Gas. The results of the natural gas fuel vapor exposure measurements are shown in Table 2. The methane measurements were made during the evening of January 13, 1994, over a period of about two to three hours during one regular evening fueling that started about 8:00 p.m. Winds during the evening were nearly calm.

Figure 2 shows a record of the methane concentration on the fueling island in the breathing zone of the fueler during the fueling of four natural gas-powered vans. The time at which the fuel connection was made and removed are shown by the legends “make” and “break” on the graph. The data show that a small amount of natural gas escaped when the fuel connection was made, and a slightly larger amount of natural gas escaped when the fuel connection was broken. During the fueling itself, there was no measurable gas release.

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Table 2. Results of Natural Gas Vapor Sampling

Sample Location	Methane Concentration, ppm
In fueler breathing zone during fueling	20-100
Near fuel nozzle during fueling	20-1,000
Compressor skid, east side	5-10
Compressor skid, west side	15-20
Compressor skid, north side	50-60
Compressor skid, south side	40-50
Cascade area	<5

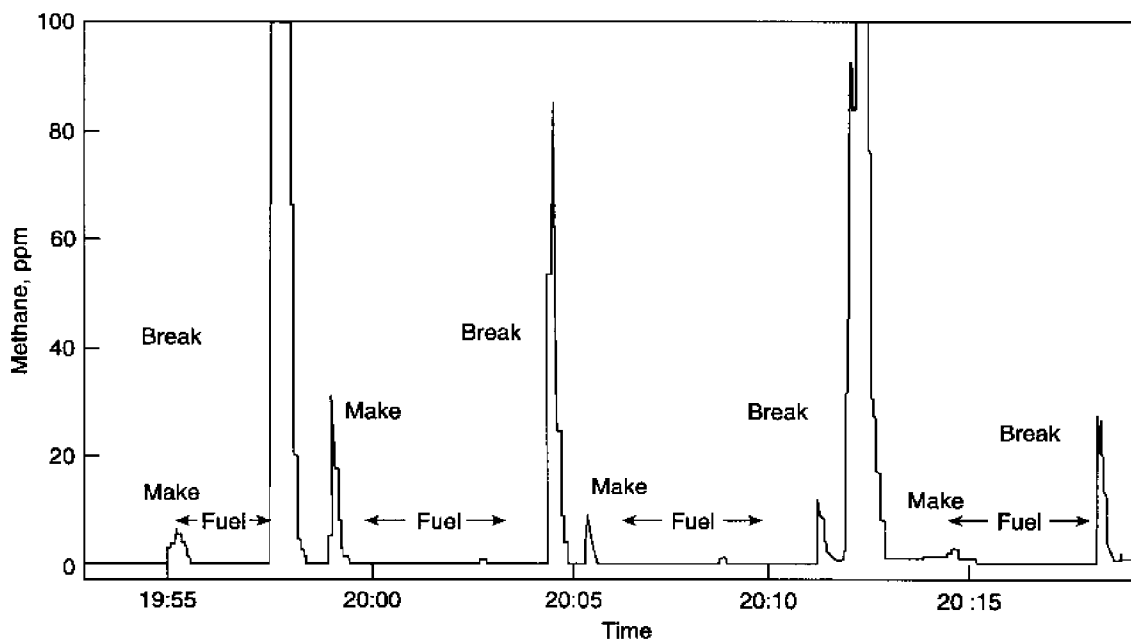


Figure 2. Methane Concentration in CNG Vehicle Fueling Area
Time Format = Hr:Min

Propane Gas. The results of the propane vapor sampling are summarized in Table 3. Propane vapor measurements were made during the evening of January 11, 1994, over a period of two to three hours during an evening fueling that started about 8:00 p.m. Winds with gusts to 30 km/hr were directed toward the side of the van opposite the fuel connection. Thus, the fuel vapor concentrations were measured in the lee of the van being fueled.

Table 3. Results of Propane Vapor Sampling

Sample Location	Propane Concentration, ppm
Near fuel nozzle during fueling	>2,000
In fueler breathing zone during fueling	10-1,000
Inside parked propane-fueled trucks	11-44

Figure 3 shows a record of the propane gas concentration in the breathing zone of the fueler during four successive fuelings. Note some vapor was released when the fuel connection was made, and a slightly larger release occurred when the fuel connection was broken. During the fueling itself, the open vent produced a small but continuous vapor release.

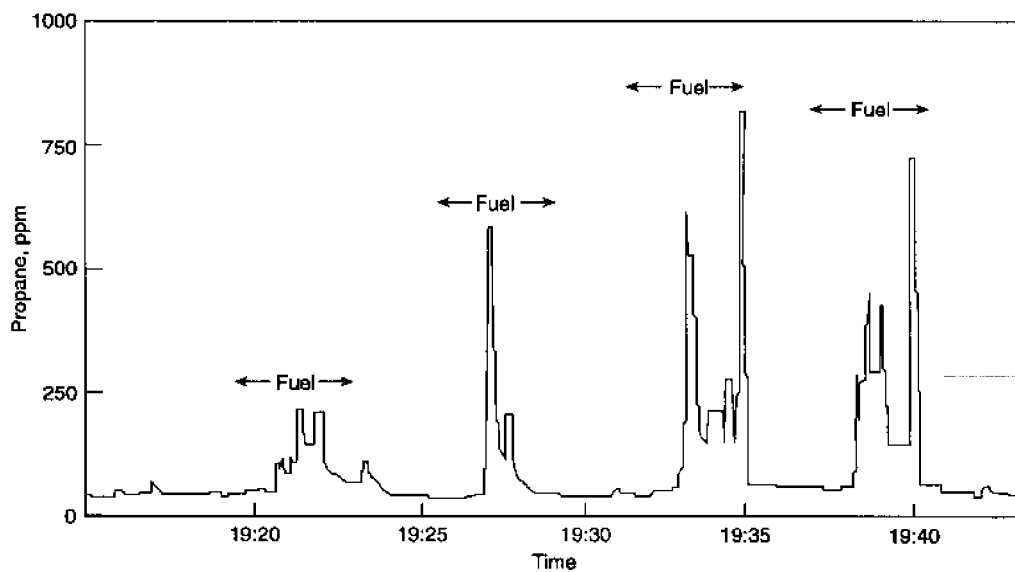


Figure 3. Propane Gas Concentration in Propane Vehicle Fueling Area
Time Format = Hr:Min

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Methanol M-85. Table 4 summarizes the results of the methanol vapor measurements. These measurements were made January 10, 1994, over a period of about two hours during an evening fueling that started about 8:00 p.m. A light wind, less than 8 km/hr, was blowing from the dispenser toward the vehicle being fueled.

Table 4. Results of Methanol Vapor Measurements

Sample Location	Methanol Concentration, ppm
Vicinity of fuel tank and fuel dispenser, no fueling taking place	<2
In fueler breathing zone during fueling	0-40
In fueler breathing zone during fueling (small fuel spill at end of fill)	300
Near exhaust from recently started vehicle (about one meter away)	1,200
Near exhaust from vehicle after warm-up (about one meter away)	160

Figure 4 shows a record of the methanol vapor concentration in the breathing zone of the fueler during two successive fuelings of M-85 CleanFleet vans. At the end of the first fill, a small amount of fuel (perhaps 50 to 100 mL) was spilled due to poor positioning of the fill nozzle. The second fill shown was more typical. No other spillage of fuel was observed during the fueling of the balance of the M-85 fleet.

Phase 2 Reformulated Gasoline. Table 5 summarizes the results of the gasoline vapor measurements. The gasoline vapor measurements were made during two regular evening fuelings. In both cases, winds were light, about 2 to 4 km/hr. Vehicles from both the reformulated gasoline and the regular unleaded fleets were fueled during these fuelings.

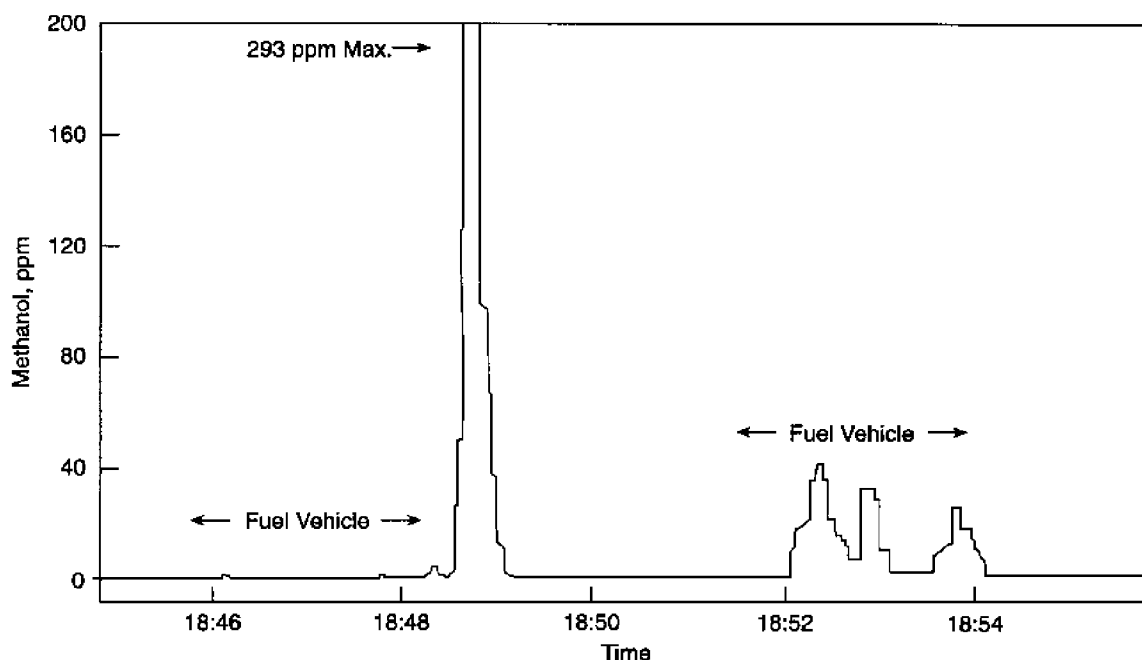


Figure 4. Methanol Vapor Concentration During Fueling
Time Format = Hr:Min

Table 5. Results of Gasoline Vapor Measurements

Sample Location	Date	Species Measured	Concentration, ppm
In fueler breathing zone while fueling RFG vehicles	1/12/94	Octane (paraffin HC)	Peak range: 20-200 Typical level: 4
In fueler breathing zone while fueling unleaded gasoline vehicles	1/12/94	Octane (paraffin HC)	Peak range: 150-800 Typical level: 20-35
In fueler breathing zone while fueling RFG vehicles	10/3/94	MTBE	Peak range: 0.3-0.4 Typical level: 0.1
In fueler breathing zone while fueling unleaded gasoline vehicles	10/3/94	MTBE	Peak range: 2-7 Typical level: 0.9

Figure 5 shows the paraffin hydrocarbon levels, measured as octane, for two successive fuelings of RFG vans. Figure 6 shows similar data for three successive fuelings of unleaded gasoline vans.

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Note that not only were the peak levels higher during fueling with regular unleaded gasoline, but the background levels in the vicinity of the fueling island became elevated. The odor of gasoline connected with this condition was quite noticeable.

Figures 7 and 8 compare, using the same vertical scale, the concentrations of MTBE in the air in the fuelers' breathing zone during fuelings with RFG and with regular unleaded gasoline. Figure 9 shows a comparison of the MTBE levels resulting from two successive fuelings of vehicles from the regular unleaded and reformulated gasoline fleets. All MTBE vapor sampling was done during the time that an oxygenate was required to be added to all gasoline sold in the Los Angeles area.

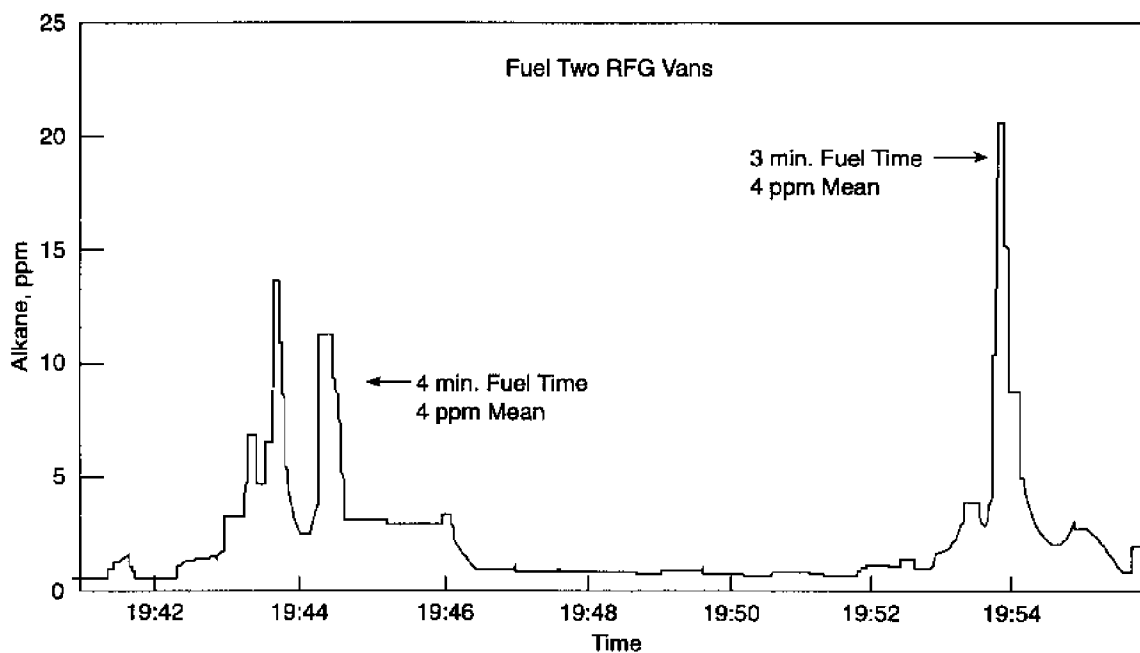


Figure 5. Paraffin Hydrocarbon Levels for Two Successive Fuelings of RFG Vans.
Time Format = Hr:Min

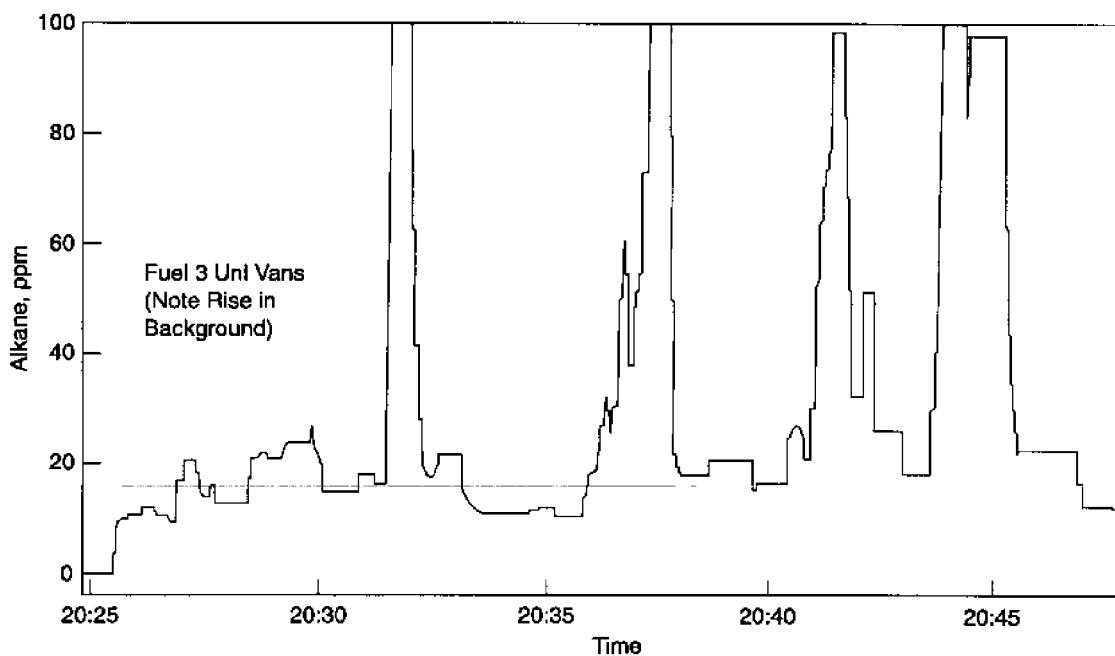


Figure 6. Paraffin Hydrocarbon Levels for Three Successive Fuelings of Unleaded Gasoline Vans. Time Format = Hr:Min

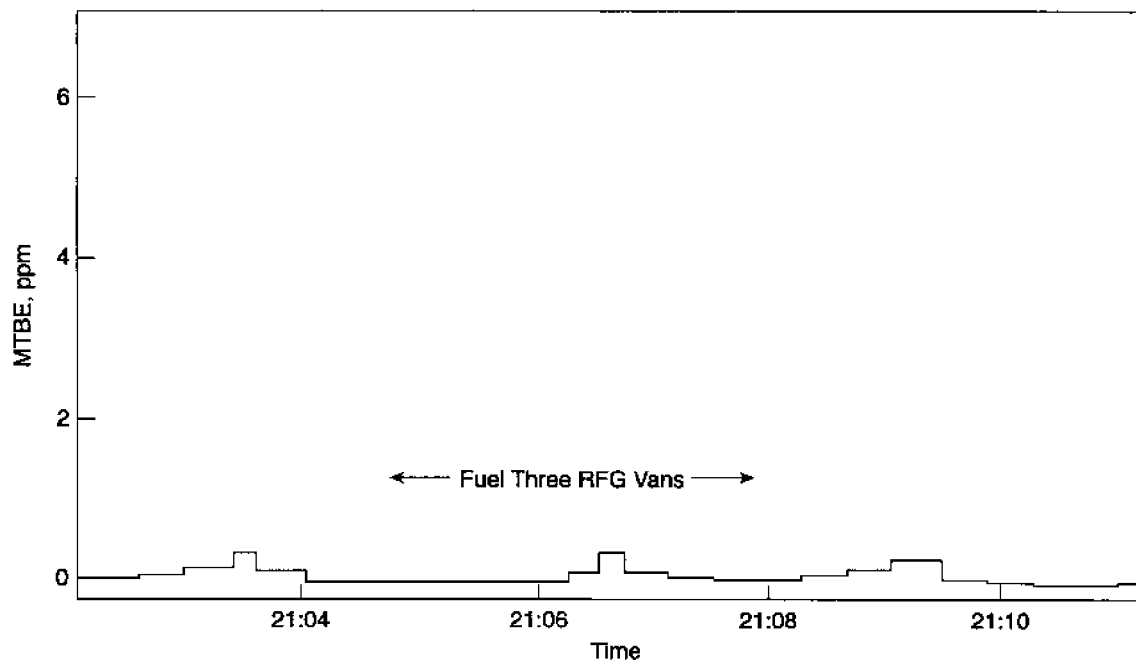


Figure 7. MTBE Vapor Levels During Three Successive Fuelings of RFG Vans. Time Format = Hr:Min

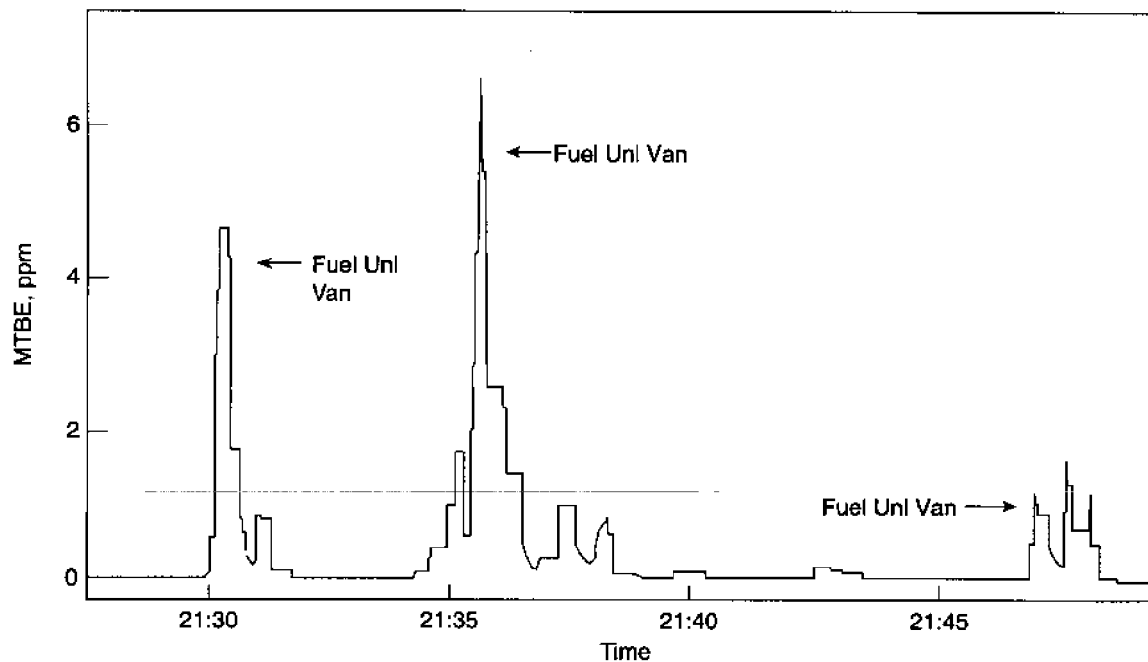


Figure 8. MTBE Vapor Levels During Three Successive Fuelings of Unleaded Gasoline Vans. Time Format = Hr:Min

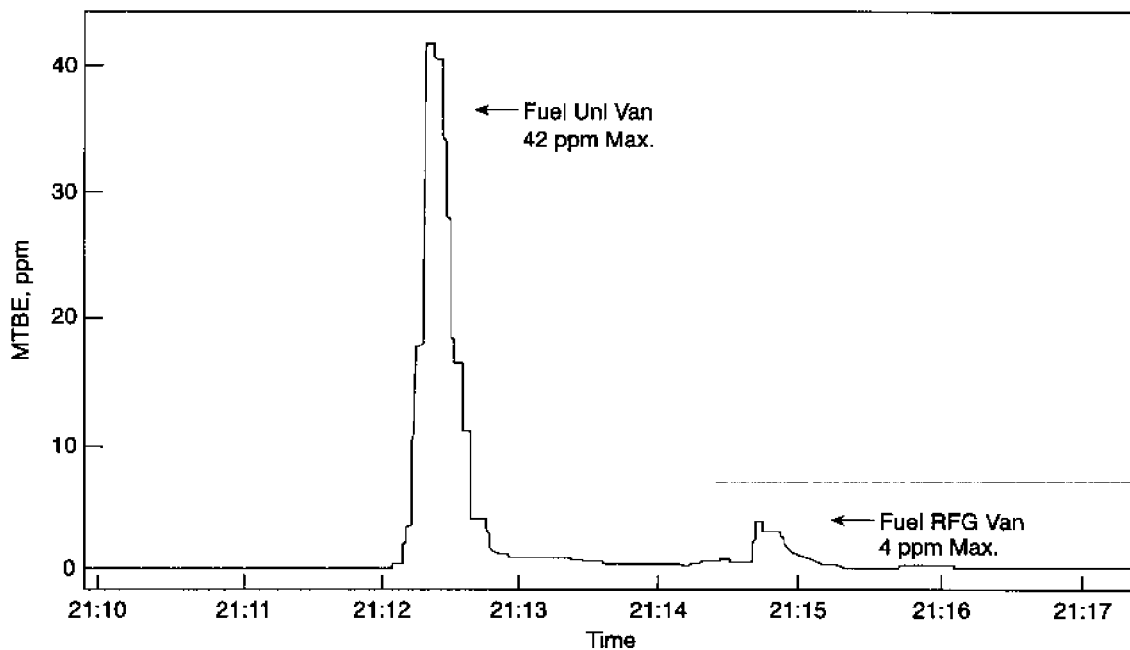


Figure 9. Comparison of MTBE Levels During Two Successive Fuelings of Unleaded and Reformulated Gasoline Vans. Time Format = Hr:Min

Results of Indoor Air Quality Measurements

Formaldehyde. The formaldehyde sampling results are summarized in Table 6.

Table 6. Summary of Formaldehyde Sampling Results

Site	Fuel	Sample Location	Sample Time	Formaldehyde Concentration, ppm
Irvine ^(a)	CNG	On building column near belt, midway down length of belt. Height 2 m above floor.	Prior to start-up	0
		On building column near belt, midway down length of belt. Height 2 m above floor.	During peak of start-up activity	0.13
		On building column near belt, near end of belt. Height 2 m above floor.	Prior to start-up	0
		On building column near belt, near end of belt. Height 2 m above floor.	During peak of start-up activity	0.12
Santa Ana ^(b)	M-85	On building column near belt, midway down length of belt. Height 2 m above floor.	During peak of start-up activity	0.17
		On building column near belt, near end of belt. Height 2 m above floor.	During peak of start-up activity	0.41

^(a) Sampling at Irvine was performed during the morning of September 13, 1994.

^(b) Sampling at Santa Ana was performed during the morning of September 15, 1994.

Carbon Monoxide. For each of the locations studied, a continuous record was made of the carbon monoxide concentrations, and the average measured carbon monoxide concentration was determined for the highest 15-minute period. Table 7 shows a summary of the results of the carbon monoxide measurements at various locations. The measurements were made during the morning start-up and pull-out on the date indicated.

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Table 7. Results of Carbon Monoxide Measurements

Site	Fuel	Sample Location	Sample Date	CO Concentration, ppm, highest 15 min
Irvine	CNG	Middle of belt	9/13/94	12
Irvine	CNG	Near end of belt	10/4/94	35
Santa Ana	M-85	Near end of belt	9/15/94	23
Los Angeles	RFG	Opposite beginning of belt	9/14/94	25

Discussion of Fuel Vapor Results

Although project resources limited the number of measurements that could be made, all measurements were taken under conditions believed to be typical of FedEx operations with the various alternative fuel fleets. The measurements made during the CleanFleet study were compared to existing guidelines. Comments for specific fuels follow.

Natural Gas. The principal components of natural gas, methane and ethane, are considered by both the American Conference of Governmental Industrial Hygienists (ACGIH)* and the Occupational Safety and Health Act (OSHA) to be “simple asphyxiants” in that they are toxic only at levels where the air is diluted such that insufficient oxygen is available for breathing. This would require about 140,000 ppm of methane. However, methane is flammable at concentrations greater than 50,000 ppm. Inasmuch as breathing a flammable mixture also constitutes a health hazard, this represents a limit for methane exposure. Natural gas also contains other components that have listed threshold limit values (TLVs). Considering these other components, the effective TLV for a typical natural gas is about 10,000 to 15,000 ppm, depending on the composition of the gas.

Even the peak levels observed for natural gas fuel vapor concentrations were at least an order of magnitude below the limits listed above. Overall, the level of natural gas exposures associated with the use of compressed natural gas vehicles at FedEx was extremely low.

* The ACGIH publishes consensus limit values called “threshold limit values” (TLVs) for a time-weighted average (TWA) over an 8-hour workshift. While ACGIH recommendations do not have the force of law, they are recognized as good industrial hygiene practice.

Propane Gas. The hydrocarbon propane is the principal component of propane fuel. Like methane, propane is considered by the ACGIH to be a “simple asphyxiant.” However, propane is flammable at concentrations greater than 21,000 ppm. Since breathing a flammable mixture also constitutes a health hazard, this represents a limit for allowable propane exposure. The OSHA PEL* for propane is 1,000 ppm. A search of the literature and informal discussions with the National Institute for Occupational Safety and Health (NIOSH)** staff did not produce any information that explained the difference between the ACGIH classification and the OSHA PEL for propane.

Some of the observed propane vapor concentrations exceeded 1,000 ppm for short periods of time—a few minutes. However, the overall time-averaged exposure of fuelers to propane vapor is estimated to be much less than the OSHA PEL.

The presence of low levels of propane in the vehicle interiors is indicative of small fuel system leaks. While the levels measured were less than one percent of the amount needed to be flammable, the presence of small amounts of propane is a reminder that fuel system components must be designed to prevent leaks and must be maintained with care.

Methanol. Methanol may be absorbed into the body via inhalation as well as through skin exposure. Methanol is then either excreted or is oxidized to formic acid. Toxicity may develop if formic acid is formed faster than it can be metabolized to carbon dioxide and water. Thus, limited exposures to methanol are not harmful, but larger exposures can overwhelm the ability of the body to remove the formic acid. The ACGIH TLV and the OSHA PEL for methanol are both 200 ppm. There is also a short-term exposure limit (STEL) of 250 ppm, which applies to a 15-minute average.

Although there were brief excursions above 250 ppm, these lasted only a few minutes. When averaged over either the 15-minute or the 8-hour time periods, the FedEx fuelers’ methanol vapor exposure would be well below the ACGIH/OSHA limits. Even close to the vehicle exhaust, the methanol concentrations were less than 200 ppm, except for the first few minutes after engine start-up.

Gasoline. Table 8 shows recommended exposure limits for various gasoline components. Neither the ACGIH nor OSHA has established recommended limits for workplace exposure to MTBE. The ACGIH has established a recommended limit for gasoline vapor.

* OSHA regulations include workplace exposure limits known as personal exposure limits (PELs). These limits have the force of law.

**

The National Institute for Occupational Safety and Health (NIOSH) is the research branch of the U.S. Public Health Service that is charged with the responsibility for developing information and guidance on workplace safety and health.

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Table 8. Recommended Exposure Limits for Various Gasoline Components

Gasoline Component	ACGIH TLV, ppm	OSHA PEL, ppm
Pentane	600	1,000
Hexane	50	500
Heptane	400	500
Octane	300	500
Benzene	0.1	10
Toluene	50	200
Gasoline Vapor	300	--

Pentane, hexane, heptane, and octane are all paraffin hydrocarbons. Because the hydrocarbon exposure measurements were made at an infrared absorption band common to all paraffin hydrocarbons, the measured values shown in Table 5 represent a total of the paraffin hydrocarbons listed in Table 8, plus many other branched chain hydrocarbons. Given the magnitude of the observed values and the time required for fueling, it is unlikely that the 8-hour TLV was exceeded for any of the paraffin hydrocarbon components for either the RFG or the regular unleaded gasoline.

The overall vapor exposure from RFG was reduced significantly compared to that from unleaded gasoline. Moreover, MTBE vapor levels from RFG (oxygenated with 10.5 percent MTBE) were about 10 times less than from winter unleaded gasoline (oxygenated with 15 percent MTBE). This difference is especially important because a number of FedEx employees considered vapor exposures from winter unleaded gasoline to be unacceptable.

Discussion of Indoor Air Quality Results

Formaldehyde. Aldehydes, including formaldehyde, are a class of chemicals formed by the incomplete oxidation (burning) of fuels.* Incomplete combustion can occur because there is simply not enough oxygen, as when a poorly tuned engine is running rich. But aldehydes are also formed when the combustion of the fuel is quenched before it can be completed. This happens when a flame contacts a cold metal surface, such as the cylinder walls and piston of an engine when the engine is first started and is still relatively cold. Catalytic converters can remove aldehydes by completing the oxidation to carbon dioxide and water. However, catalytic converters are not effective until they reach their operating temperature. Thus, the full benefit of catalytic converters is not available during start-up and pull-out.

* Aldehydes can also be formed outdoors in smog through photochemical reactions.

For each fuel there is a corresponding aldehyde that has the same number of carbon atoms as the original fuel. Two of the CleanFleet fuels, natural gas (mostly methane) and M-85 (mostly methanol) are composed mainly of chemical constituents with one carbon atom. Both of these fuels are chemical precursors of formaldehyde, which also has one carbon atom. Other fuels can also form aldehydes. However, the current ACGIH and OSHA health exposure guidelines for these aldehydes are about 100 times higher and so are of much less concern than formaldehyde exposure.

Formaldehyde is a volatile substance with a sharp, irritating odor. Formaldehyde causes irritation of the skin, eyes, and respiratory tract. For some individuals, repeated exposure to formaldehyde can cause sensitization, the development of an immune response to even small amounts of a chemical. The odor of formaldehyde can be detected at concentrations of 0.05 to 1 ppm.⁽⁴⁾ Both ACGIH and NIOSH have set standards or made recommendations for workplace exposure to formaldehyde. The specific recommendations are as follows:

- The ACGIH has set a ceiling value of 0.3 ppm for formaldehyde.⁽⁵⁾ A ceiling value is a limit that may not be exceeded. Formerly, the ACGIH set a time-weighted average (TWA) of 1 ppm and a STEL (15-minute) of 2 ppm for formaldehyde.
- The current OSHA PEL for formaldehyde is 0.75 ppm, with an action level of 0.5 ppm.⁽⁶⁾ Levels above the action level trigger several OSHA requirements including regular workplace monitoring, installation of a medical surveillance program, and fairly extensive record keeping. The OSHA STEL is 2 ppm for a 15-minute sampling period.

The results of the air sampling carried out at the FedEx alternative fuel demonstration sites using CleanFleet vehicles indicate that, in general, formaldehyde levels were not excessive compared to current guidelines. However, one measurement near the M-85 vehicles at the Santa Ana demonstration site was above the 0.30 ppm ACGIH guideline. Comments from employees confirmed that objectionable eye, nose, and throat irritation was often present at the Santa Ana site. However, it should be noted that the catalysts were optimized for gasoline, rather than for M-85 exhaust.

CO. CO acts to preferentially bind to hemoglobin in the blood, thereby preventing that portion of the blood from carrying oxygen to the body. The ACGIH TLV for CO is 25 ppm, the OSHA PEL is 50 ppm.

The limited measurements of CO made during the morning start-up and pull-out at the Irvine, Santa Ana, and downtown Los Angeles CleanFleet demonstration sites all showed indoor levels of CO well within OSHA guidelines. Even the 15-minute period with the highest average concentration did not exceed the recommended 8-hour time-weighted average.

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Overall Conclusions

- The measured exposures to CNG, propane gas, and M-85 fuel vapors were all extremely low compared to recommended standards. Thus, there is little likelihood of occupational hygiene problems occurring due to exposure to these fuels during normal fleet-fueling activities.
- A comparison of measured exposures to MTBE from reformulated gasoline with 10.5 percent MTBE and from winter unleaded gasoline with 15 percent MTBE, using the same model vehicles and adjacent pumps on the same fueling island, showed that the fueler exposures to MTBE were at least 10 times lower for RFG compared with those for winter unleaded gasoline.
- A comparison of exposures to reformulated gasoline vapors and to regular unleaded gasoline vapors also showed overall exposures to paraffin hydrocarbons were lower for RFG than for regular unleaded gasoline.
- The levels of formaldehyde concentration during the morning start-up and pull-out at the Irvine CNG location were less than half of the ACGIH STEL. However, indoor measurements of formaldehyde during morning start-up of the methanol vans were higher, and one measurement exceeded the ACGIH STEL. These higher levels are consistent with complaints from couriers at the Santa Ana site about eye, nose, and throat irritation during the morning start-up.
- Exposure to CO was found to be within accepted workplace exposure limits.

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References

1. *Methods of Air Sampling and Analysis*, Third Edition, James P. Lodge, Editor. p. 279ff.
2. “Indoor/Outdoor Measurements of Formaldehyde and Total Aldehydes,” by Chin-I Lin, Roy N. Anaclerio, Douglas W. Anthon, Leah Z. Fanning and Craig D. Hollowell, Lawrence Berkeley Laboratory Publication LBL-9397, (1979). p. 3.
3. A formaldehyde collection efficiency of 84% is listed in *Methods of Air Sampling and Analysis*, Third Edition, James P. Lodge, Editor, p. 282, and collection efficiency of 80% is listed in “Indoor/Outdoor Measurements of Formaldehyde and Total Aldehydes,” by Chin-I Lin, Roy N. Anaclerio, Douglas W. Anthon, Leah Z. Fanning and Craig D. Hollowell, Lawrence Berkeley Laboratory Publication LBL-9397, (1979). However, though the impinger solution volumes were the same, the air flow rates of 0.5 and 0.94 L/min, respectively, were much larger than the 0.2 L/min used in the present work.
4. *Indoor Air Quality and Human Health*, Isaac Turiel, Stanford University Press, 1989. p. 18.
5. “Threshold Limit Values and Biological Exposure Indices for 1992-93,” The American Conference of Governmental Industrial Hygienists.
6. 29 CFR 1910.1048.